Periprosthetic femoral fractures following total hip and total knee arthroplasty

Authors: Samuel W King[a], Jonathan N Lamb[a, b], Emily S Cage[a, c], Hemant Pandit[a, b]

[a] Department of Trauma and Orthopaedics, Leeds General Infirmary, Great George Street, Leeds, LS1 3EX, UK

[b]Leeds Institutes of Rheumatology and Musculoskeletal Medicine, University of Leeds, Chapel Allerton Hospital, Chapeltown Rd, Leeds, LS7 4SA, UK

[c]Indiana University School of Medicine, 340 West 10th Street, Indianapolis, IN 46202, USA

Corresponding Author:

Name: Jonathan Lamb

Email: umjnl@leeds.ac.uk

Address: Leeds Institutes of Rheumatology and Musculoskeletal Medicine, University of Leeds, Chapel Allerton Hospital, Chapeltown Rd, Leeds LS7 4SA

Abstract

Total joint arthroplasties are increasing worldwide in both frequency and prevalence. When successful, they offer great improvements in quality of life. However, fractures around implants are often difficult to manage and require prolonged inpatient stays in tertiary hospitals. Management may differ between surgeons, but most patients will be managed surgically if mobility or joint stability is threatened. Those affected are often at higher risk from surgery, are frailer and at higher risk of mortality and a lifelong reduction in mobility. The incidence of these fractures is increasing, and patients should appreciate the risk and implications of this recognised complication of joint arthroplasty.

Abbreviations:
THA Total hip arthroplasty
TKA Total knee arthroplasty
PFF Periprosthetic femoral fracture
BMI Body mass index
ORIF Open reduction internal fixation

Keywords
Total hip arthroplasty

This is the author's manuscript of the article published in final edited form as:
King, S. W., Lamb, J. N., Cage, E. S., & Pandit, H. (2018). Periprosthetic femoral fractures following total hip and total knee arthroplasty. Maturitas, 117, 1–5. https://doi.org/10.1016/j.maturitas.2018.08.010

Total hip arthroplasty
Periprosthetic fracture
Femur
Complication

1. Introduction

There is increasing demand for total knee arthroplasty (TKA) and total hip arthroplasty (THA). The reasons are multifactorial and include an ageing population, expanding indications for THA and a population-level increase in body mass index (BMI) [1]. Quantitative estimates of the increase in the annual numbers vary: Kurtz et al project a 137% increase in demand for THA (from 208,600 to 572,000 a year) and a 601% increase for TKA (from 450000 to 3.48 million a year) in the US between 2005 and 2030, while Culliford et al estimate an increase from 75,366 to 95,877 THAs a year and from 76,497 to 118,666 TKAs a year in the UK from 2012 to 2035[1,2].

Periprosthetic fractures are defined as fractures around orthopaedic implants[3]. Following TKA and THA, periprosthetic fractures may affect the pelvis, femur, tibia or patella. This review will focus on periprosthetic fractures of the femur (PFF) following TKA or THA. The risk of post-operative fracture is 0.3-2.5% following TKA [4–6] and 0.4-3.5% following THA[7,8]. The population incidence of PFF is expected to increase with the growing number of patients undergoing joint arthroplasty[9].

Many parallels exist between patients with PFF and patients with a fracture to the neck of the femur. Patients with PFF are likely to be old and frail and often require major complex surgery to restore mobility[10]. Following this procedure, there is a 16.5% risk of reoperation due to surgical failure[11]. As a result, PFFs are associated with an increased mortality rate (11-13.2% one-year post-operatively), approximately 2.1% higher for men and 1.2% higher for women at age 70 when compared with individuals not affected by a PFF[11–13]. Although these fractures affect a small proportion of all primary joint arthroplasties, against the background of a large prevalence, periprosthetic fractures are a significant health burden on the population and financial cost for health services[3,14].

This review will discuss the incidence of PFFs and patient and surgical risk factors. There will be brief discussion of the fracture of other bones. We will review the current evidence pertaining to epidemiology, fracture types and their management, the impact of these fractures on the morbidity and mortality of patients, and the financial impact of PFFs on healthcare services.

2. Methods

The following terms were used to conduct an extensive search of the literature on the PubMed database up to 14 May 2018: ((((((“fracture*”[All Fields]) AND “periprosthetic”[All Fields])) or fracture, periprosthetic[MeSH Terms])) AND ((((((“tibia*”[All Fields]) OR “femur”[All Fields]) OR “femoral”[All Fields]) OR “hip”[All Fields]) OR “knee”[All Fields]) OR “patella*”[All Fields])) AND ((“arthroplast*”[All Fields]) OR “replacement”[All Fields])) AND fracture*[Title/Abstract]. The results were limited to articles published in English, which were screened for those most relevant to the study of periprosthetic fractures around total joint arthroplasties. The reference sections of articles included were also searched to ensure relevant publications had not been missed.

3. Incidence

3.1. Fractures following THA

Fractures of the proximal femur associated with THA may be intra-operative or post-operative. The distinction is informative as it often indicates the mechanism of fracture and will affect the management. Intra-operative fractures typically occur during forceful preparation and insertion of a metallic implant into the proximal femur. This is necessary to provide stability but can easily lead to fracture. Post-operative fractures invariably occur following a low-energy fall from standing height and frequently require surgery to restore mobility.

THAs may be fixed to the femur with or without bone cement. Cemented THAs rely on a layer of bone cement between implant and bone for fixation, while the femoral components of cementless THAs are wedged into position following femoral canal preparation and undergo osseointegration over the following months. Older literature finds rates of intra-operative fracture for cementless THA to be 3-5.4%[15,16], and rates for cemented THA to be 0.1-2.5%[15,17,18]. A cohort study by Abdel et al of 32644 primary total hip arthroplasties at a single academic centre in the United States conducted over the course of 40 years found that 1.7% of patients had intra-operative fractures [7]. Interestingly, they differentiated between stem types and reported that intra-operative fractures occurred in 3.0% of cementless stems but only 0.23% of cemented stems, equating to a hazard ratio of over 13.

The cumulative incidence of post-operative fractures varies considerably. Lindahl et al report a cumulative incidence of 0.4% following primary THA in their national Swedish cohort study of 1049 patients with PFF over 21 years with data collected from the Swedish National Hip Arthroplasty Register [8]. Also, the National Joint Registry 2017 for England, Wales and Northern Ireland records a revision rate of 0.67 per 1000 patient years due to periprosthetic fractures[20]. Meanwhile, Cook et al found a ten-year cumulative incidence of 3.5% in their single-centre study of 6458 primary THAs over a 17-year period[19]. Abdel et al report a ten-year incidence following primary THA of 1.6%, which is very similar to the 1.7% reported by Meek et al in their Scottish cohort study of 52,136 primary THAs. Abdel et al also report a 20-year incidence of 3.5%[7]. Given that theirs was a single-centre study, Abdel et al may underestimate rates of PFF as those managed at other centres are less likely to be reported. The disparity between national registry and other published data may arise because only PFFs which underwent reoperation were included in the Swedish registry, while only those revised were included in the UK registry data, excluding those which underwent conservative management in both, and open reduction and internal fixation (ORIF) in the UK registry. The incidences of PFF depend on several factors, including the use of cemented stems, patient demographics and the follow-up period.

PFF rate is much higher following revision THA. A single-centre cohort study of 5417 revision THAs reported intra-operative fractures in 12%, with three times as many occurring in cementless THAs[21]. Post-operative fractures occurred in 11% after 20 years, with no difference between cemented and cementless.

3.2. Fractures following TKA

Fractures associated with TKAs may affect the distal femur (supracondylar fractures), the proximal tibia or the patella. This section of the review focuses on fractures of the distal femur, reflecting clinical impact and coverage in the literature. The incidence of supracondylar periprosthetic fractures in the UK is increasing in line with the increasing numbers of TKAs performed per year[10]. The incidence following primary TKA is reported to be 0.3-2.5%[5,22,23]. The incidence following revision surgery varies greatly, from 1.6% to 38% in a literature review by Whitehouse et al[24]. A recent cohort study by Meek et al of over 40,000 TKAs found the ten-year cumulative incidence of supracondylar fractures to be 1.3% for primary TKAs and 2.2% for revision procedures[10]. The National Joint Registry 2017 data suggest a lower revision rate for periprosthetic fracture, of 0.15 per 1000 patient years[20]. As with periprosthetic fractures around hips, this is likely to be an underestimation, as those fractures treated conservatively or with ORIF are not reported. Tibial fractures occur in 0.4% of primary procedures, and the incidence is higher in revision surgery[25], when intra-operative fractures are more common[24]. Patellar fractures have been found in 0.68-1.19% of TKAs[26,27], but this is likely ti be an underestimate, as a significant proportion are asymptomatic and often not associated with a traumatic event[26]. Of note, a review of the literature by Chalidis et al found less than 1% of patellar fractures occurred in patients without resurfaced patellas[27].

4. Risk factors

The risk factors for periprosthetic fractures are important to understand when counselling patients and investigating novel approaches to prevention and treatment. Risk factors for periprosthetic fracture can be broadly divided into patient-related and surgery-related categories.

4.1. Patient-related risk factors

Advanced age and female gender are frequently described as risk factors for PFFs due to reduced bone quality in these patients[28]; however, these findings are not entirely consistent throughout the literature. Wu et al found a significant association between patient age and increased fracture risk following cementless THA in their study of 425 patients over three years[29], and Meek et al found increased risk of fracture with increasing age following TKA and THA[10]. Conversely, while they found an increased risk of intra-operative fracture during cementless THA in older patients, Abdel et al found no significant association between patient age and risk of post-operative fractures in their study encompassing 17466 uncemented THAs, although they do not describe how they control for those patients who die during the follow-up period[7]. Singh et al found a bimodal relationship between patient age and PFF risk following 17633 TKAs in one centre over a 19 year period, with those under 60 and over 80 years of age at the highest risk[30].

There are similar controversies regarding patient gender. Meek et al found increased risk of fracture in female patients following TKA or THA across 96647 primary arthroplasties[10], while Lindahl et al found no association of risk of fracture following THA with gender in 321 patients with PFF[31]. Of note, the latter study recorded fractures using a reoperation database, and so did not include those managed conservatively. Thien et al found increased risk of fracture for women with cementless THA and reduced risk for those with cemented THA in a study of a database of 437,629 patients[32]. The increased use of corticosteroids and higher activity levels (and therefore opportunities for trauma) in younger patients are suggested to be confounding factors[30,33].

Other risk factors specifically relate to bone health. Osteoporosis is a well-recognised risk factor for periprosthetic fractures[33]. Wu et al found osteoporosis, as quantified by Singh's index, to be associated with risk of fracture following THA[29], and Beals and Tower showed that a significant proportion of patients with PFF have osteopenia or previous fragility fractures[34]. Merkel and Johnson described increased risk of periprosthetic fracture following TKA in patients with osteoporosis in their study of 34 patients with periprosthetic supracondylar fractures[5]. As may be expected, patients who undergo THA due to hip fracture are more likely have a subsequent periprosthetic fracture[35]. Inflammatory arthropathies have been associated with increased risk[5,8], perhaps due to associated osteopenia, concurrent comorbidities and steroid use [36].

4.2. Surgery-related risk factors

Intra-operative and post-operative periprosthetic fractures are more likely around cementless implants [7]. Long-term stability in cementless THAs is dependent on a process of fixation between implant and bone called osseointegration, but initial stability relies on the generation of frictional forces between the implant and the bone, and it is during this period that cementless THAs are at greatest risk of periprosthetic fracture[37]. The majority of intra-operative fractures occur during insertion of the femoral stem, with increased risk in female and older patients as both of these groups are more likely to have poorer bone quality[7,32]. These findings suggest that the incidence of intra-operative PFFs is increased by forceful placement of the femoral component, which is common during cementless THA. Interestingly, gender and age do not influence intra-operative periprosthetic fracture in cemented THA, where forceful instrumentation of the proximal femur is far less common [7]. The majority of post-operative fractures occur within the first six months, with the revision rate for cementless stems reported to be ten times that of cemented stems [32]. The overall rate of post-operative fractures 20 years after THA was found to be 3.5%, again with a greater incidence following cementless THA (7.7%) than after cemented THA (2.1%)[7].

With cementless implants, there are subdivisions by shape of the femoral component. A systematic review by Carli et al showed that two subtypes of implant (single- and double-wedge) have increased rates of PFF, suggesting the geometry of the implant is a factor, in addition to the method of insertion [38]. Regarding cemented implants, polished tapered stems, which are designed to wedge in a cement mantle in the proximal femur, were associated with a greater incidence of PFF than others.

Femoral notching is a common surgical error resulting from accidental perforation of the anterior femur during TKA surgery. This has been implicated as a risk factor for supracondylar periprosthetic fractures. In biomechanical cadaveric studies, Lesh et al found reduced torsional and bending strength in ten human femurs with full-thickness anterior cortical notches when compared with those without[39]. However, these findings have not been replicated in clinical studies. Ritter et al found no increased incidence in those with femoral notching in a study of over 1000 TKAs[40]. Gujarathi et al similarly found no association in their radiographic analysis of 200 TKAs followed up for a mean of nine years[41]. If there is a causal relationship between femoral notching and PFFs, a much larger study would be required to provide adequate power[28]. Poor operative technique, including component malpositioning, malalignment and excessive resection, is also associated with increased risk of fracture[28].

5. Fracture classification and management

Management of periprosthetic fractures aims to restore mobility, reduce pain and improve quality of life. Given the rare and complex nature of periprosthetic fractures, variable degrees of local surgical experience may be available, without clear consensus for management. As a general principle, stable undisplaced fractures around implants and fractures involving bone which is not involved in direct weight bearing can be managed non-operatively; displaced fractures are managed with ORIF; loose components are fixed with revision procedures; and those with insufficient bone stock require more complex management.
As with most fracture types, there are several recognised systems of classification for periprosthetic fractures. The most useful are those which have good inter-observer fidelity and which guide management.

PFFs can be classified as using the A, B, C method of the Unified classification system (figure 1): **A**pophyseal fractures of periarticular muscle attachments (e.g. trochanteric); fractures extending into the **B**ed of the bone implant interface; and fractures which are **C**lear of or distal to the implant.

Type A fractures are rarely involved in the direct transfer of body weight through the hip and can be treated non-operatively with a period of non-weight-bearing[42]. If displaced, they may be treated by tension band wiring[43]. If the fracture is caused by osteolysis from implant wear, polyethylene exchange may be required after fracture healing[43]. “Clamshell” fractures in this region were described more recently and usually occur intra-operatively. They require revision if the implant is loose[44].

B-type fractures are in the region of the implant–bone interface and are further divided into three subtypes. B_1 are stable and usually require ORIF[45]; in B_2 fractures the implant is loose, and revision arthroplasty is required[46]; in B_3 the implant is loose with inadequate bone remaining, and management can include proximal femoral replacement and bone grafting[47]. C-type fractures are below the implant, and can often be treated with ORIF if far enough away from the distal end of the implant to allow adequate plating[47].

Supracondylar femoral fractures around TKAs can be classified in a similar way using the universal system outlined above.

6. Morbidity and Mortality

Risk of mortality following PFF is comparable to that following neck of femur fractures. Older patients and those with a higher BMI are more likely to die following periprosthetic femoral fractures, and overall post-operative mortality is 11-17.7%; 13% will require re-operation[3,12,48,49]. Griffiths et al found a 30-day mortality of 10% and major complications in 23% in their cohort of sixty operatively managed proximal periprosthetic fractures, with worse outcomes in those with a delay to surgery of more than 72 hours and an Abbreviated Mental Test Score (AMTS) of 8 or less[50]. Bhattacharyya et al found one-year mortality rates of 2.9% following primary joint arthroplasty, 11% following surgical treatment of PFF, and 16.5% after primary hip fracture in their case-control study of 726 patients[12]. Similarly, Shields et al analysed the fracture registry at their centre over a three-year period and found a mortality rate of 17.7% in the year following periprosthetic fracture, as compared with 21.2% for native neck-of-femur fractures[3]. In addition to a risk of death, the impact of these fractures on quality of life is significant due to a prolonged reduction in mobility. Despite appropriate surgical management, patients generally do not return to the same level of mobility, have worse hip scores and are in more pain than prior to their fracture[51].

7. Financial Implications

The financial implications of periprosthetic fractures are significant. For all periprosthetic fractures of the femur, a US study found an average in-hospital cost of $24,800 per PFF[3]. A study from a large UK teaching hospital of 146 patients found the median in-hospital cost of proximal PFF (following THA or hemiarthroplasty) to be £23,500[14], significantly higher than the average cost of managing a patient with a fractured neck of femur at the same hospital (£12,200), perhaps representing the significant implant and other surgical costs[52]. Average stay was 38 days; ward costs accounted for the majority of expenses (80%), and cost was significantly increased when further surgery was required[14]. A more recent Welsh study of 90 periprosthetic hip fractures found a mean cost of £31,370 and a length of stay of 43 days[53]. Revision arthroplasty was associated with reduced length of stay, faster mobilisation and overall lower costs. Mortality at six months was 10%, in keeping with rates reported in the literature.

A nationwide US study found that patients admitted with fractures around TKA treated with ORIF cost $25,500 and with revision TKA cost $37,700 on average, as compared with $16,900 for primary TKA[54]. Length of stay was also significantly increased as compared with primary TKA, and rates of readmission within 90 days were over 20% for either method of surgical management of periprosthetic fracture.

These figures underestimate the true cost of periprosthetic fractures, given the requirement for social care, outpatient care, adaptations to reduced mobility and further operative management which are not included in these papers.

8. Conclusions

Periprosthetic fractures associated with TKA and THA occur in a small number of patients but represent a significant risk of mortality and morbidity. This review focused mainly on periprosthetic fractures of the femur. The incidence of these events is increasing with a greater prevalence of arthroplasty in the population, and post-operative PFF occurs in approximately 3% of all femoral arthroplasty patients, with rates much higher following revision surgery. The risk of death is reported in the literature as being in excess of 10%, and very few patients return to baseline function, comparable with that of patients with a native fracture to the neck of the femur. Management of PFF involves significant financial costs, much higher than the cost involved in the management of patients with neck-of-femur fracture, with the majority of costs relating to prolonged hospital stay. Some of the risk factors for periprosthetic fractures are patient-related. Reduced bone health seen in steroid use, inflammatory arthropathy and osteoporosis is associated with increased PFF rates. The prevalence of the latter factor is increased in older, female patients, leading to suggestions that age and gender are themselves independent risk factors. However, increased incidence of fracture in these groups is not reported entirely consistently throughout the literature. Other factors relate to the surgery and implants themselves, with cementless stems for THA presenting a higher risk of PFF, and certain femoral components presenting at higher risk of fracture than others. Management of periprosthetic fractures depends on the displacement of the fracture, the effects of the fracture on the implant, and the remaining bone stock available. Management for more complex fractures has a less clear consensus, and the choice of technique may depend on individual surgeon preference or ability. Given the importance of weight bearing, especially in more frail patients, non-operative management is generally reserved for undisplaced, stable fractures and non-ambulatory patients. Outcomes are better for patients who are managed promptly and are therefore able to weight bear earlier, and so patients with PFF should be treated with similar priority to patients with neck-of-femur fracture. A medical and orthopaedic multi-disciplinary team approach is crucial to early recognition and prompt treatment of patients to reduce morbidity. Little is known about the specific modifiable risk factors for patient mortality and morbidity, and so further work is required to identify key targets to improve the morbidity and mortality of these patients in the acute hospital setting. This work must be used to establish key guidelines and standards of care which may improve the care and survival of patients with periprosthetic fracture.

Contributors

Samuel W Kinga drafted the original article, and participated in the review and editing, and methodology.

Jonathan N Lamb participated in the methodology, writing, review and editing, and supervision.

Emily S Cage participated in the writing, review and editing.

Hemant Pandit participated in the conceptualization, writing, review and editing, supervision, and methodology.

All authors saw and approved the final version.

Conflict of interest

Jonathan N Lamb's contribution is supported by grants from The Emily Parkinson Trust and the Sir John Charnley Trust.

The other authors declare that they have no conflict of interest.

Funding

This project received no direct funding.

Provenance and peer review

This article has undergone peer review.

References

[1] D. Culliford, J. Maskell, A. Judge, C. Cooper, D. Prieto-Alhambra, N.K. Arden, COASt Study Group, Future projections of total hip and knee arthroplasty in the UK: results from the UK Clinical Practice Research Datalink, Osteoarthritis Cartilage. 23 (2015) 594–600. doi:10.1016/j.joca.2014.12.022.

[2] S. Kurtz, K. Ong, E. Lau, F. Mowat, M. Halpern, Projections of primary and revision hip and knee arthroplasty in the United States from 2005 to 2030, J. Bone Joint Surg. Am. 89 (2007) 780–785. doi:10.2106/JBJS.F.00222.

[3] E. Shields, C. Behrend, J. Bair, P. Cram, S. Kates, Mortality and Financial Burden of Periprosthetic Fractures of the Femur, Geriatr. Orthop. Surg. Rehabil. 5 (2014) 147–153. doi:10.1177/2151458514542281.

[4] R.K. Aaron, R. Scott, Supracondylar fracture of the femur after total knee arthroplasty, Clin. Orthop. (1987) 136–139.

[5] K.D. Merkel, E.W.J. Johnson, Supracondylar fracture of the femur after total knee arthroplasty, J. Bone. 68 (1986) 29–43.

[6] C.H. Rorabeck, J.W. Taylor, Periprosthetic fractures of the femur complicating total knee arthroplasty, Orthop. Clin. North Am. 30 (1999) 265–277.

[7] M.P. Abdel, C.D. Watts, M.T. Houdek, D.G. Lewallen, D.J. Berry, Epidemiology of periprosthetic fracture of the femur in 32 644 primary total hip arthroplasties: a 40-year experience, Bone Jt. J. 98-B (2016) 461–467. doi:10.1302/0301-620X.98B4.37201.

[8] H. Lindahl, H. Malchau, P. Herberts, G. Garellick, Periprosthetic femoral fractures classification and demographics of 1049 periprosthetic femoral fractures from the Swedish National Hip Arthroplasty Register, J. Arthroplasty. 20 (2005) 857–865. doi:10.1016/j.arth.2005.02.001.

[9] N.P. Hailer, G. Garellick, J. Kärrholm, Uncemented and cemented primary total hip arthroplasty in the Swedish Hip Arthroplasty Register, Acta Orthop. 81 (2010) 34–41. doi:10.3109/17453671003685400.

[10] R.M.D. Meek, T. Norwood, R. Smith, I.J. Brenkel, C.R. Howie, The risk of peri-prosthetic fracture after primary and revision total hip and knee replacement, J. Bone Joint Surg. Br. 93 (2011) 96–101. doi:10.1302/0301-620X.93B1.25087.

[11] B. Füchtmeier, M. Galler, F. Müller, Mid-Term Results of 121 Periprosthetic Femoral Fractures: Increased Failure and Mortality Within but not After One Postoperative Year, J. Arthroplasty. 30 (2015) 669–674. doi:10.1016/j.arth.2014.11.006.

[12] T. Bhattacharyya, D. Chang, J.B. Meigs, D.M.I. Estok, H. Malchau, Mortality After Periprosthetic Fracture of the Femur, JBJS. 89 (2007) 2658. doi:10.2106/JBJS.F.01538.

[13] H. Lindahl, A. Oden, G. Garellick, H. Malchau, The excess mortality due to periprosthetic femur fracture. A study from the Swedish national hip arthroplasty register, Bone. 40 (2007) 1294–1298. doi:10.1016/j.bone.2007.01.003.

[14] J.R.A. Phillips, C. Boulton, C.G. Morac, A.R.J. Manktelov, What is the financial cost of treating periprosthetic hip fractures?, Injury. 42 (2011) 146–149. doi:10.1016/j.injury.2010.06.003.

[15] D.J. Berry, Epidemiology: hip and knee, Orthop. Clin. North Am. 30 (1999) 183–190.

[16] J.T.J. Schwartz, J.G. Mayer, C.A. Engh, Femoral fracture during non-cemented total hip arthroplasty, J. Bone. 71 (1989) 1135–1142.

[17] H. Lindahl, Epidemiology of periprosthetic femur fracture around a total hip arthroplasty, Injury. 38 (2007) 651–654. doi:10.1016/j.injury.2007.02.048.

[18] G. Löwenhielm, L.I. Hansson, J. Kärrholm, Fracture of the lower extremity after total hip replacement, Arch. Orthop. Trauma Surg. 108 (1989) 141–143. doi:10.1007/BF00934256.

[19] R.E. Cook, P.J. Jenkins, P.J. Walmsley, J.T. Patton, C.M. Robinson, Risk factors for Periprosthetic Fractures of the Hip: A Survivorship Analysis, Clin. Orthop. 466 (2008) 1652–1656. doi:10.1007/s11999-008-0289-1.

[20] National Joint Registry, National Joint Registry 14th Annual Report, 2017. http://www.njrreports.org.uk/Portals/0/PDFdownloads/NJR%2014th%20Annual%20Report%202017.pdf (accessed October 8, 2018).

[21] M.P. Abdel, M.T. Houdek, C.D. Watts, D.G. Lewallen, D.J. Berry, Epidemiology of periprosthetic femoral fractures in 5417 revision total hip arthroplasties: a 40-year experience, Bone Jt. J. 98-B (2016) 468–474. doi:10.1302/0301-620X.98B4.37203.

[22] W.L. Healy, J.M. Siliski, S.J. Incavo, Operative treatment of distal femoral fractures proximal to total knee replacements, J. Bone Joint Surg. Am. 75 (1993) 27–34.

[23] M.A. Ritter, P.M. Faris, E.M. Keating, Anterior femoral notching and ipsilateral supracondylar femur fracture in total knee arthroplasty, J. Arthroplasty. 3 (1988) 185–187.

[24] M.R. Whitehouse, S. Mehendale, Periprosthetic fractures around the knee: current concepts and advances in management, Curr. Rev. Musculoskelet. Med. 7 (2014) 136–144. doi:10.1007/s12178-014-9216-0.

[25] N.A. Felix, M.J. Stuart, A.D. Hanssen, Periprosthetic fractures of the tibia associated with total knee arthroplasty, Clin. Orthop. (1997) 113–124.

[26] C.J. Ortiguera, D.J. Berry, Patellar fracture after total knee arthroplasty, J. Bone Joint Surg. Am. 84-A (2002) 532–540.

[27] B.E. Chalidis, E. Tsiridis, A.A. Tragas, Z. Stavrou, P.V. Giannoudis, Management of periprosthetic patellar fractures. A systematic review of literature, Injury. 38 (2007) 714–724. doi:10.1016/j.injury.2007.02.054.

[28] S. Sarmah, S. Patel, G. Reading, M. El-Husseiny, S. Douglas, F. Haddad, Periprosthetic fractures around total knee arthroplasty, Ann. R. Coll. Surg. Engl. 94 (2012) 302–307. doi:10.1308/10.1308/003588412X13171221592537.

[29] C.C. Wu, M.K. Au, S.S. Wu, L.C. Lin, Risk factors for postoperative femoral fracture in cementless hip arthroplasty, J. Formos. Med. Assoc. Taiwan Yi Zhi. 98 (1999) 190–194.

[30] J.A. Singh, M. Jensen, D. Lewallen, Predictors of periprosthetic fracture after total knee replacement, Acta Orthop. 84 (2013) 170–177. doi:10.3109/17453674.2013.788436.

[31] H. Lindahl, G. Garellick, H. Regnér, P. Herberts, H. Malchau, Three hundred and twenty-one periprosthetic femoral fractures, J. Bone Joint Surg. Am. 88 (2006) 1215–1222. doi:10.2106/JBJS.E.00457.

[32] T.M. Thien, G. Chatziagorou, G. Garellick, O. Furnes, L.I. Havelin, K. Mäkelä, S. Overgaard, A. Pedersen, A. Eskelinen, P. Pulkkinen, J. Kärrholm, Periprosthetic femoral fracture within two years after total hip replacement: analysis of 437,629 operations in the nordic arthroplasty register association database, J. Bone Joint Surg. Am. 96 (2014) e167. doi:10.2106/JBJS.M.00643.

[33] J. Franklin, H. Malchau, Risk factors for periprosthetic femoral fracture, Injury. 38 (2007) 655–660. doi:10.1016/j.injury.2007.02.049.

[34] R.K. Beals, S.S. Tower, Periprosthetic fractures of the femur. An analysis of 93 fractures, Clin. Orthop. (1996) 238–246.

[35] R. Sarvilinna, H.S.A. Huhtala, R.T. Sovelius, P.J. Halonen, J.K. Nevalainen, K.J.K. Pajamäki, Factors predisposing to periprosthetic fracture after hip arthroplasty: a case (n = 31)-control study, Acta Orthop. Scand. 75 (2004) 16–20. doi:10.1080/00016470410001708030.

[36] M. Porsch, R. Galm, L. Hovy, M. Starker, F. Kerschbaumer, [Total femur replacement following multiple periprosthetic fractures between ipsilateral hip and knee replacement

in chronic rheumatoid arthritis. Case report of 2 patients], Z. Orthop. Ihre Grenzgeb. 134 (1996) 16–20. doi:10.1055/s-2008-1037412.
[37] G. Chammout, O. Muren, E. Laurencikas, H. Bodén, P. Kelly-Pettersson, H. Sjöö, A. Stark, O. Sköldenberg, More complications with uncemented than cemented femoral stems in total hip replacement for displaced femoral neck fractures in the elderly, Acta Orthop. 88 (2017) 145–151. doi:10.1080/17453674.2016.1262687.
[38] A.V. Carli, J.J. Negus, F.S. Haddad, Periprosthetic femoral fractures and trying to avoid them: what is the contribution of femoral component design to the increased risk of periprosthetic femoral fracture?, Bone Jt. J. 99-B (2017) 50–59. doi:10.1302/0301-620X.99B1.BJJ-2016-0220.R1.
[39] M.L. Lesh, D.J. Schneider, G. Deol, B. Davis, C.R. Jacobs, V.D. Pellegrini, The consequences of anterior femoral notching in total knee arthroplasty. A biomechanical study, J. Bone Joint Surg. Am. 82-A (2000) 1096–1101.
[40] M.A. Ritter, A.E. Thong, E.M. Keating, P.M. Faris, J.B. Meding, M.E. Berend, J.L. Pierson, K.E. Davis, The effect of femoral notching during total knee arthroplasty on the prevalence of postoperative femoral fractures and on clinical outcome, J. Bone Joint Surg. Am. 87 (2005) 2411–2414. doi:10.2106/JBJS.D.02468.
[41] N. Gujarathi, A.B. Putti, R.J. Abboud, J.G.B. MacLean, A.J. Espley, C.F. Kellett, Risk of periprosthetic fracture after anterior femoral notching, Acta Orthop. 80 (2009) 553–556. doi:10.3109/17453670903350099.
[42] J.W. Pritchett, Fracture of the greater trochanter after hip replacement, Clin. Orthop. (2001) 221–226.
[43] G.J. Haidukewych, J. Langford, F.A. Liporace, Revision for periprosthetic fractures of the hip and knee, J. Bone Joint Surg. Am. 95 (2013) 368–376.
[44] W.N. Capello, J.A. D'Antonio, M. Naughton, Periprosthetic fractures around a cementless hydroxyapatite-coated implant: a new fracture pattern is described, Clin. Orthop. 472 (2014) 604–610. doi:10.1007/s11999-013-3137-x.
[45] M. Moazen, J.H. Mak, L.W. Etchels, Z. Jin, R.K. Wilcox, A.C. Jones, E. Tsiridis, Periprosthetic femoral fracture--a biomechanical comparison between Vancouver type B1 and B2 fixation methods, J. Arthroplasty. 29 (2014) 495–500. doi:10.1016/j.arth.2013.08.010.
[46] H. Lindahl, H. Malchau, A. Odén, G. Garellick, Risk factors for failure after treatment of a periprosthetic fracture of the femur, J. Bone Joint Surg. Br. 88 (2006) 26–30. doi:10.1302/0301-620X.88B1.17029.
[47] M.P. Abdel, U. Cottino, T.M. Mabry, Management of periprosthetic femoral fractures following total hip arthroplasty: a review, Int. Orthop. 39 (2015) 2005–2010. doi:10.1007/s00264-015-2979-0.
[48] J.M. Drew, W.L. Griffin, S.M. Odum, B. Van Doren, B.T. Weston, L.S. Stryker, Survivorship After Periprosthetic Femur Fracture: Factors Affecting Outcome, J. Arthroplasty. 31 (2016) 1283–1288. doi:10.1016/j.arth.2015.11.038.
[49] G.S. Matharu, P.B. Pynsent, D.J. Dunlop, M.P. Revell, Clinical outcome following surgical intervention for periprosthetic hip fractures at a tertiary referral centre, Hip Int. J. Clin. Exp. Res. Hip Pathol. Ther. 22 (2012) 494–499. doi:10.5301/HIP.2012.9760.
[50] E.J. Griffiths, D.J.W. Cash, S. Kalra, P.J. Hopgood, Time to surgery and 30-day morbidity and mortality of periprosthetic hip fractures, Injury. 44 (2013) 1949–1952. doi:10.1016/j.injury.2013.03.008.
[51] L. Zheng, W.-Y. Lee, D.-S. Hwang, C. Kang, C.-K. Noh, Could Patient Undergwent Surgical Treatment for Periprosthetic Femoral Fracture after Hip Arthroplasty Return to Their Status before Trauma?, Hip Pelvis. 28 (2016) 90–97. doi:10.5371/hp.2016.28.2.90.

[52] T.M. Lawrence, C.T. White, R. Wenn, C.G. Moran, The current hospital costs of treating hip fractures, Injury. 36 (2005) 88–91; discussion 92. doi:10.1016/j.injury.2004.06.015.
[53] A.R. Jones, T. Williams, V. Paringe, S.P. White, The economic impact of surgically treated peri-prosthetic hip fractures on a university teaching hospital in Wales 7.5-year study, Injury. 47 (2016) 428–431. doi:10.1016/j.injury.2015.11.012.
[54] R.A. Reeves, W.W. Schairer, D.S. Jevsevar, Costs and Risk Factors for Hospital Readmission After Periprosthetic Knee Fractures in the United States, J. Arthroplasty. 33 (2018) 324-330.e1. doi:10.1016/j.arth.2017.09.024.

Figure Legend

Figure 1: Unified Classification System for periprosthetic fracture around total hip replacement. **A_G**: Apophyseal fracture of greater trochanter. **A_L**: Apophyseal fracture of lesser trochanter. **B_1**: Fracture into the bed of the bone with a stable implant. **B_2**: Fracture into the bed of the bone with an unstable implant. **B_3**: Fracture into the bed of the bone with an unstable implant and inadequate bone remaining. **C**: Fracture clear of the implant